Impacts of Climate Change on Hydropower Generation in California:

Different Perspectives from High and Low Elevation Systems

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PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

Agenda

- Introduction
- High elevation case studies: Upper American River Project and Big Creek
- Low elevation case study: Merced Irrigation District

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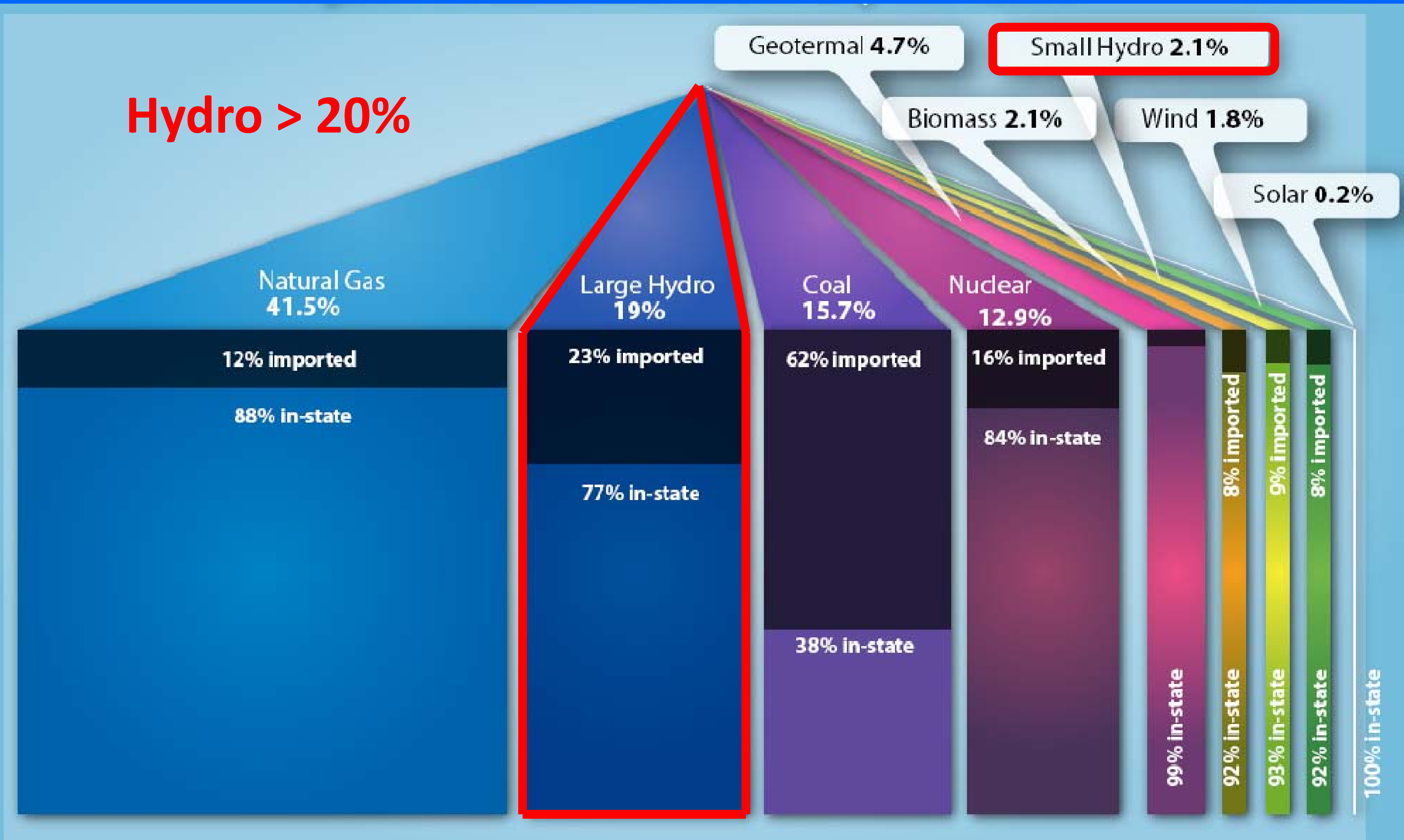
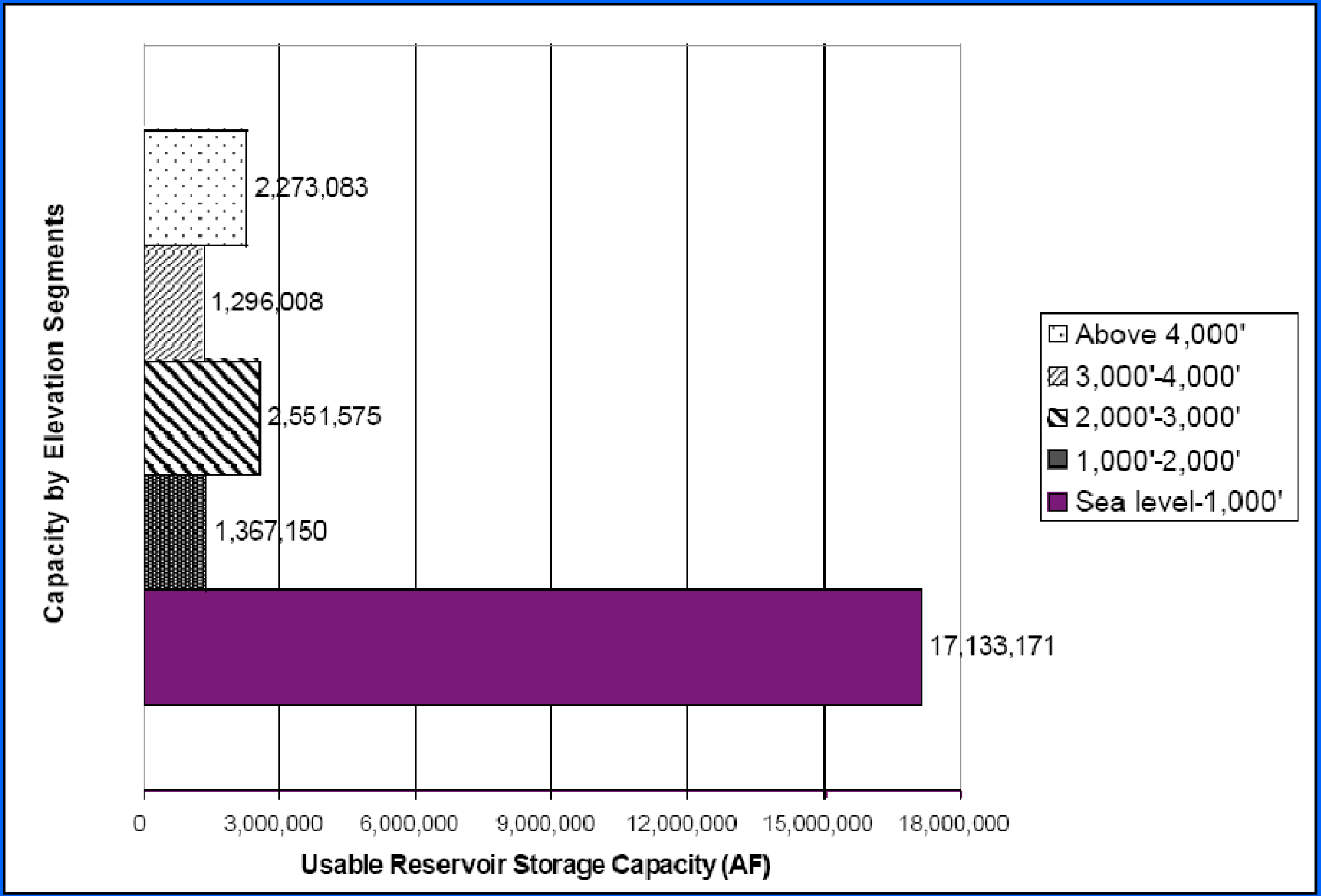
California's Electricity Mix - 2006



CEC, 2007

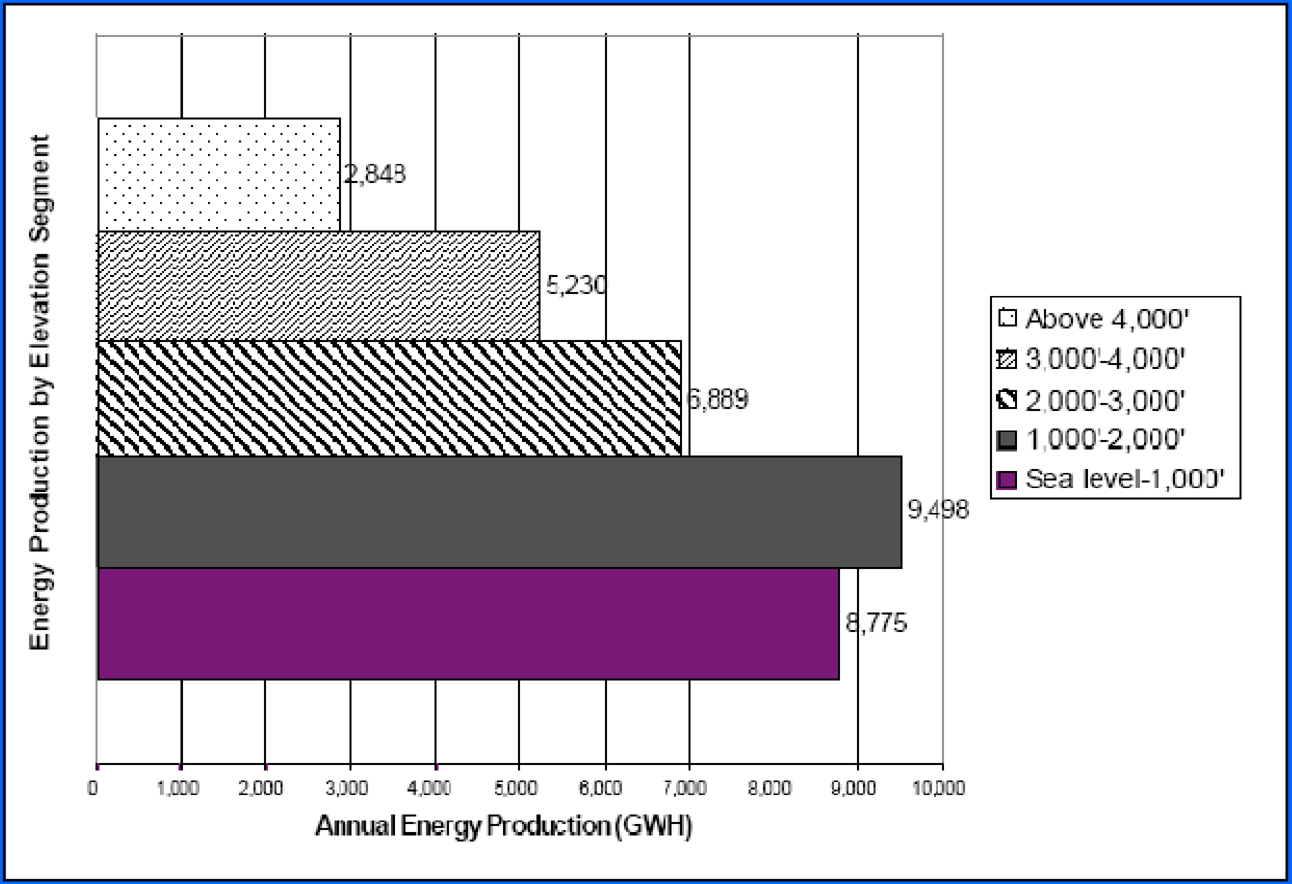
Difference between high and low elevation hydropower systems



Usable Reservoir Capacity by Elevation Segments

Aspen Environmental and M-Cubed, 2005

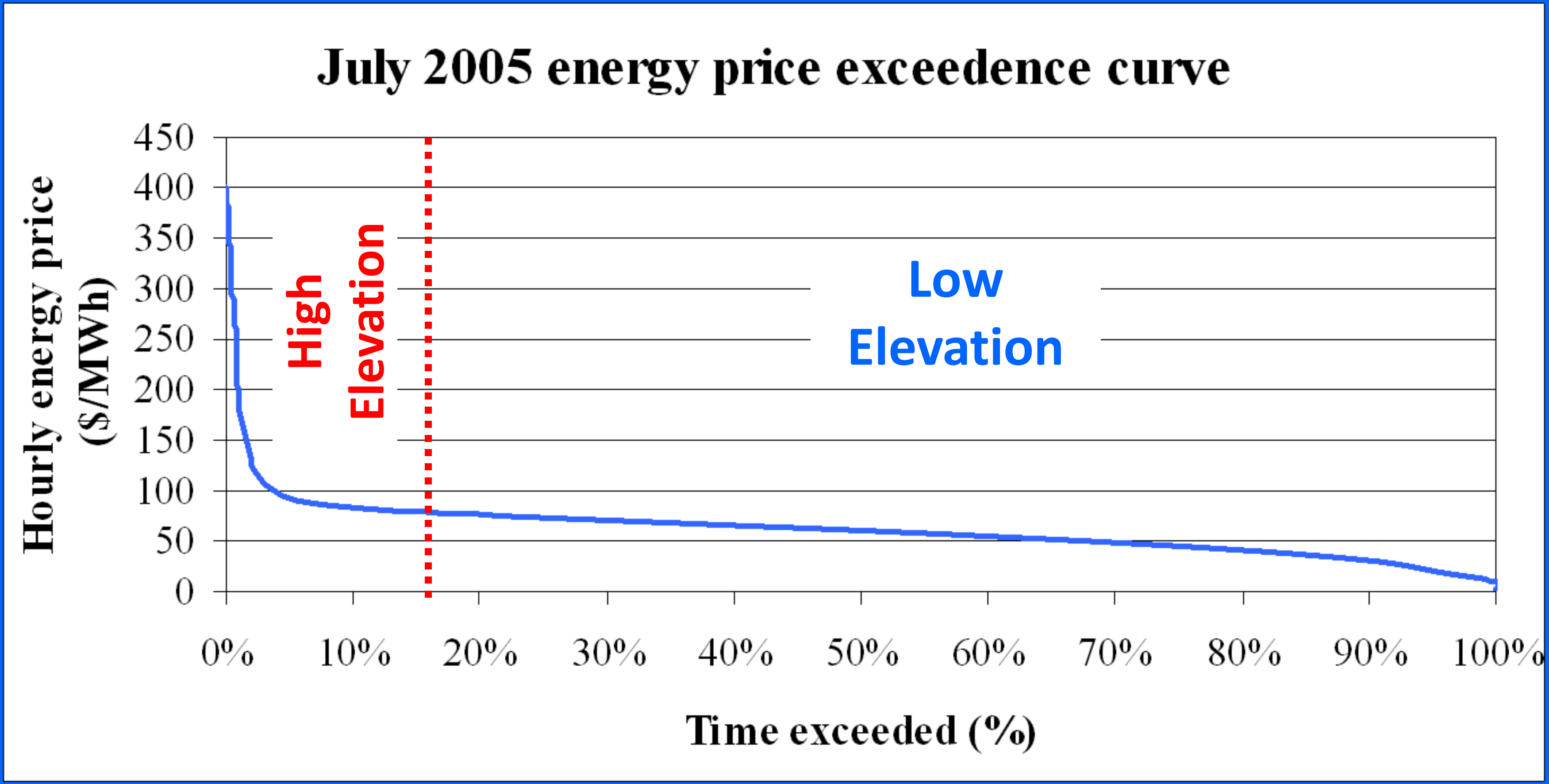
Difference between high and low elevation hydropower systems



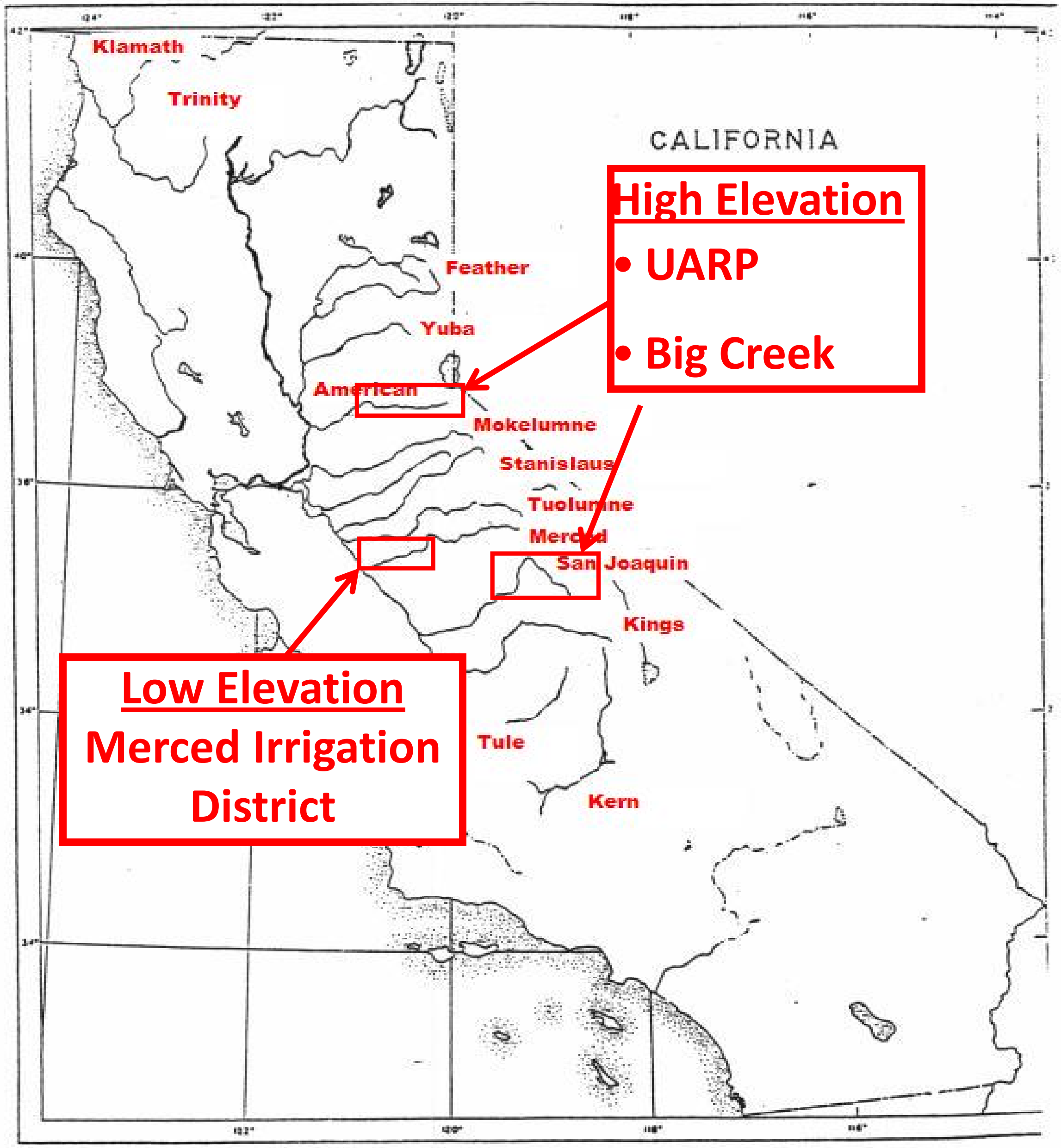
Average Annual Energy Production by Elevation Segments

Aspen Environmental and M-Cubed, 2005

Difference between high and low elevation hydropower systems



Three case studies



http://faculty.sierracollege.edu/ccox/images/maps/CA_rivers_map.jpg

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High elevation hydropower:
Two case studies

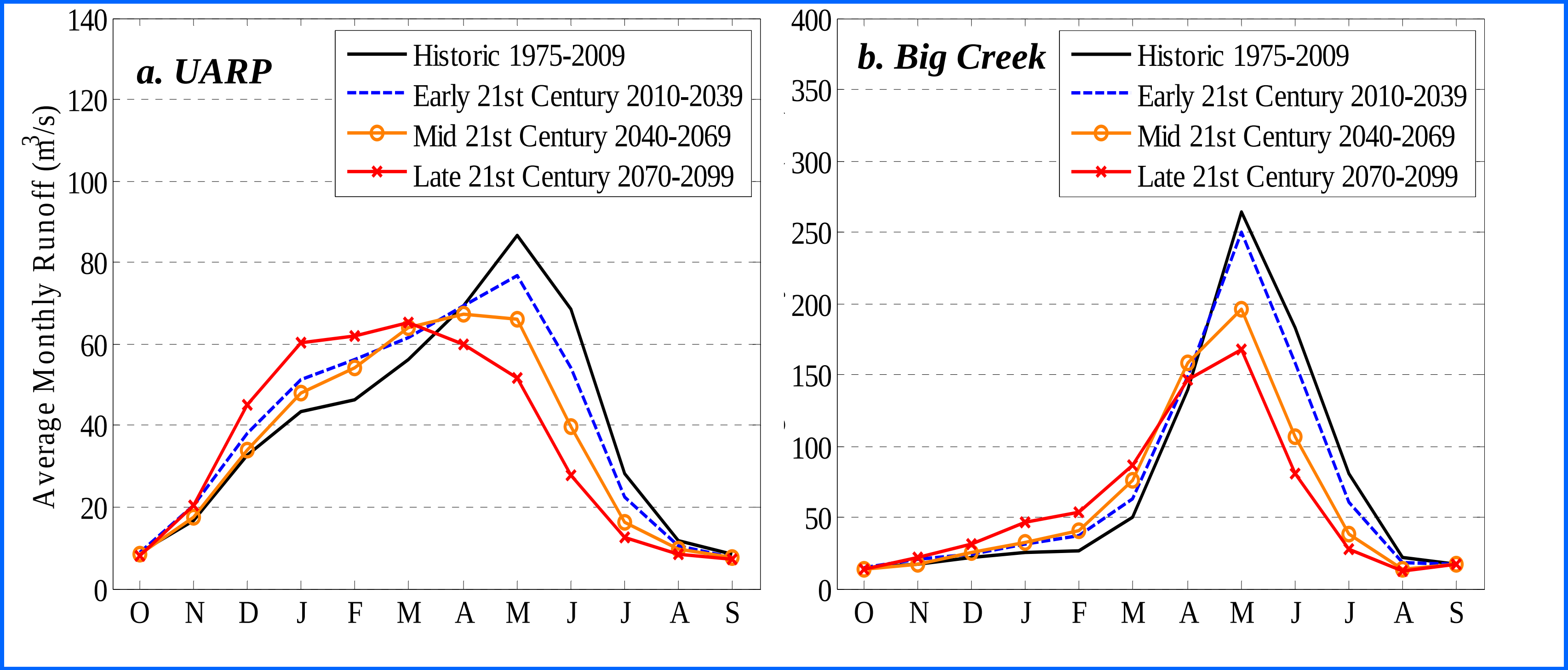
	System	
Variable	**UARP**	**Big Creek**
Operated	SMUD	SCE
Location	Upper American River	Upper San Joaquin River
Range in elevations (ft)	1,850-6,410	1,403-7,643
Storage/Inflows	0.42	0.31

- Operations simulated using LP under historic and climate change hydrologic conditions
- Objective function: energy generation revenues and storage. Calibrated to reproduce historic operations.

Climate change hydrology

Inflows to UARP and Big Creek

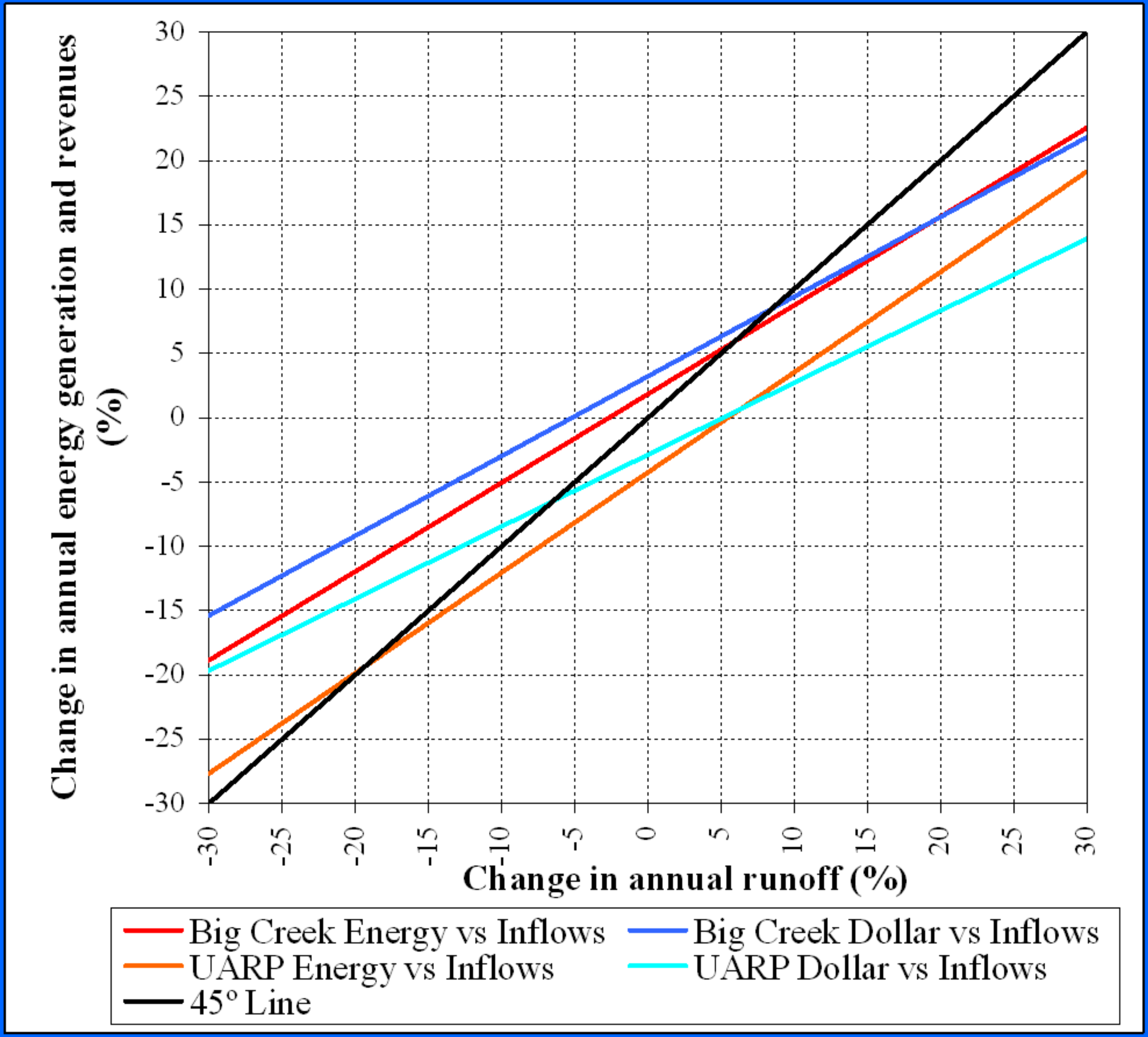
- In average annual runoff is reduced (especially for Big Creek) but with large uncertainty
- Earlier center of mass (especially for UARP)
- Larger floods in winter



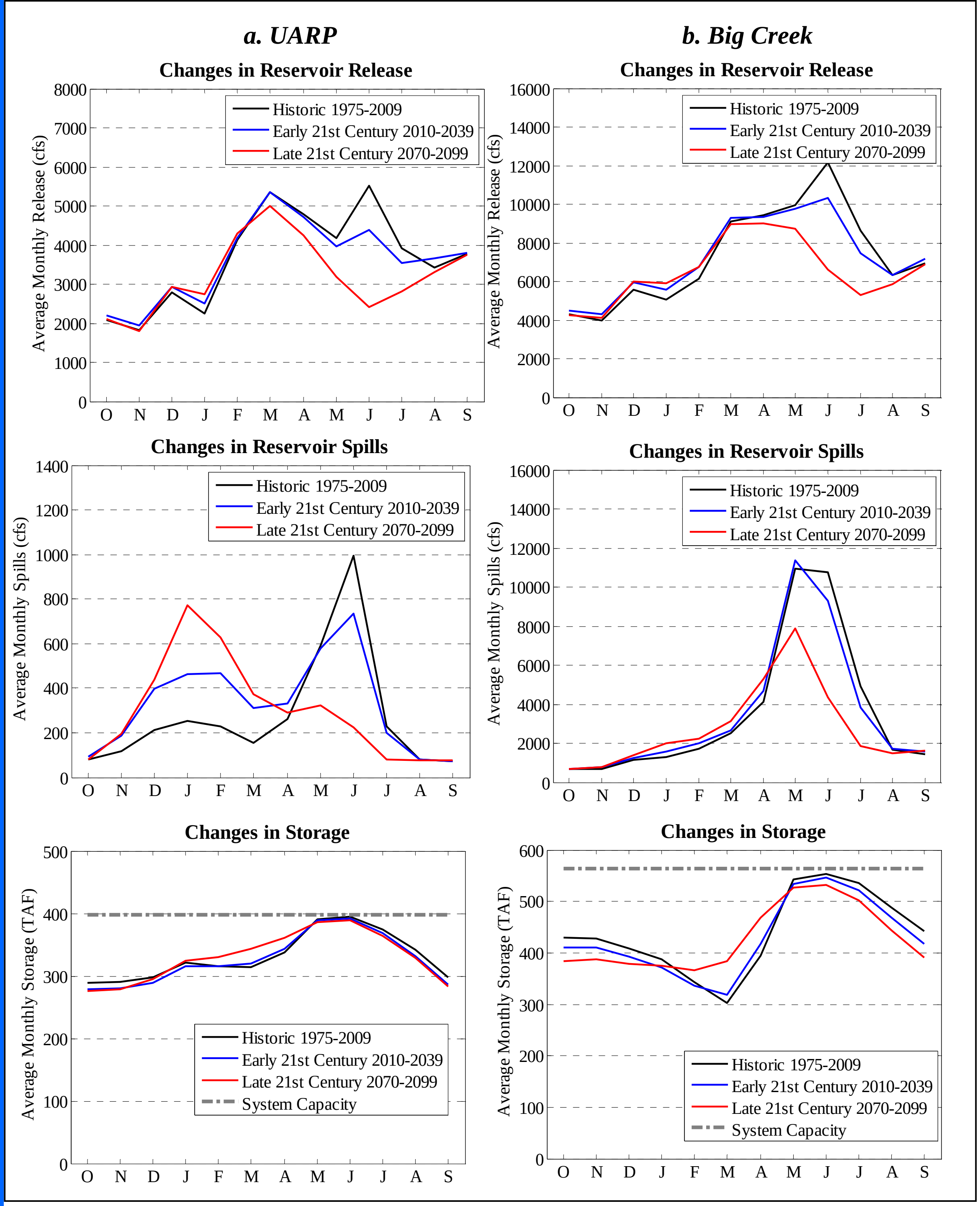
Future Operations

Variable	Period	System	
		UARP System	Big Creek System
Energy Generation in GWh/year	1960-2010	1,976	3,580
	2070-2099	-12.20%	-10.40%
Energy Generation revenues in mill $/year	1960-2010	130	212
	2070-2099	-8.50%	-7.80%
Average August Power Capacity in MW	1960-2010	654	1,034
	2070-2099	-0.10%	-0.20%
Average Spills in cfs (m^3/s)	1960-2010	269 (8)	3,447 (98)
	2070-2099	10.80%	-21.80%

Relation between change in benefits and inflows



- Reduction in release in summer
- Increase in spills in winter in UARP; Reduction of spills in Big Creek
- Summer storage mostly unaffected



Conclusions: High Elevation Hydropower

- **Hydropower generation drops** under most of climate change scenarios as a consequence drier hydrologic conditions (especially Big Creek) and increased spills (especially UARP)

- Impact due to **earlier inflows** associated with increase in temperature is more evident in lower elevation systems (UARP)

- Under most circumstances these high elevation systems are able to keep their **power capacity** close to maximum levels during late spring and summer months

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Low elevation hydropower

Variable	UARP	System Big Creek	MID
Operated	SMUD	SCE	MID-PG&E
Location	Upper American River	Upper San Joaquin River	Middle Merced River
Range in elevations (ft)	1,850-6,410	1,403-7,643	879
Storage/Inflows	0.42	0.31	1.08

- Operations simulated using SDP (Vicuna et al., 2008, 2007 CCCC conference) under historic and climate change hydrologic conditions
- Objective function: energy generation revenues (variable head), water supply. Includes flood control.

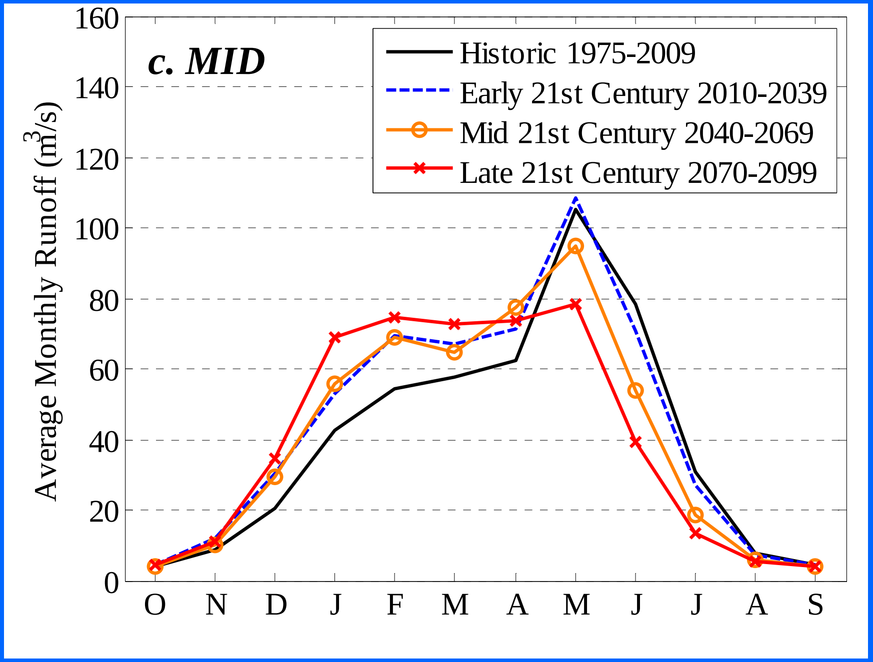
Research questions

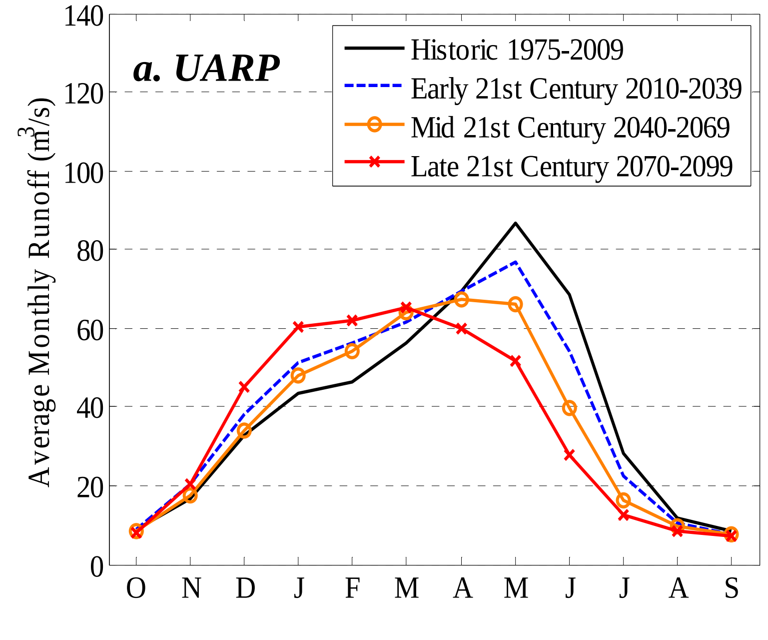
- How will climate change affect energy supply and agricultural benefits?
- What policies available to mitigate climate impacts?
  - Conjunctive use
  - New or modified Infrastructure
  - Reservoir re-operation (e.g. flood control rules)

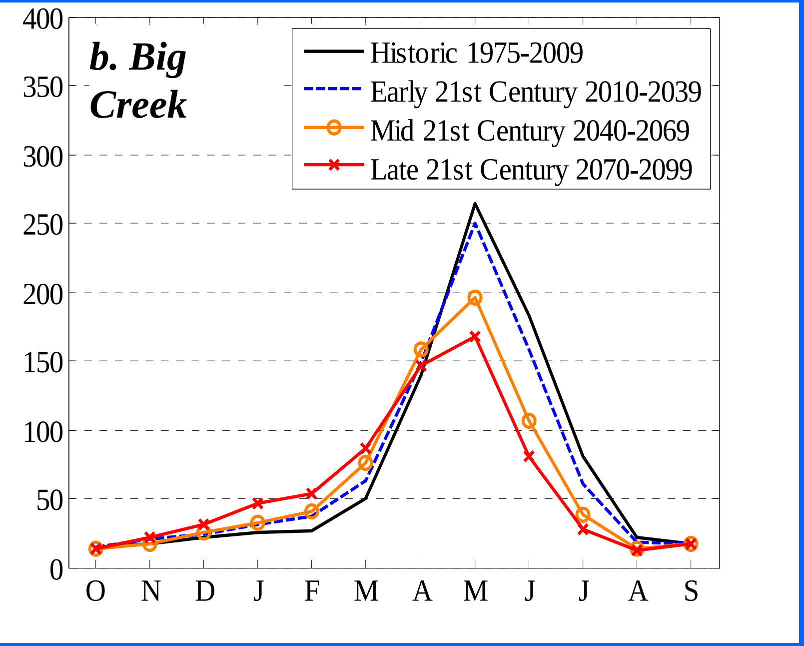
Climate change hydrology

Impacts similar to UARP

- Reduced runoff (≈11%)
- Earlier center of mass
- Larger floods in winter







Results

Variable	Period	System MID
Energy Generation in GWh/year	2011-2040	302.8
	2070-2099	-21.3 %
Energy Generation revenues in mill $/year	2011-2040	8.4
	2070-2099	-22.1 %
Average Spills in cfs (m^3/s)	2011-2040	137.4 (3.9)
	2070-2099	53.60%

Variable	Period	System MID
Groundwater Pumping in GWh/year	2011-2040	79.8
	2070-2099	46.90%
Groundwater Pumping Costs in mill $/year	2011-2040	4.8
	2070-2099	46.90%
Agriculture Benefits in mill $/year	2011-2040	24.2
	2070-2099	-2.8 %

- Unlike High Elevation system
  - Both loss in generation and revenues is larger than loss in inflows (-11%)
  - Loss in hydropower revenues larger than loss in energy generation
  - Large spills

Results

Variable	Period	System MID	Variable	Period	System MID
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	2070-2099	-21.3 %		2070-2099	46.90%
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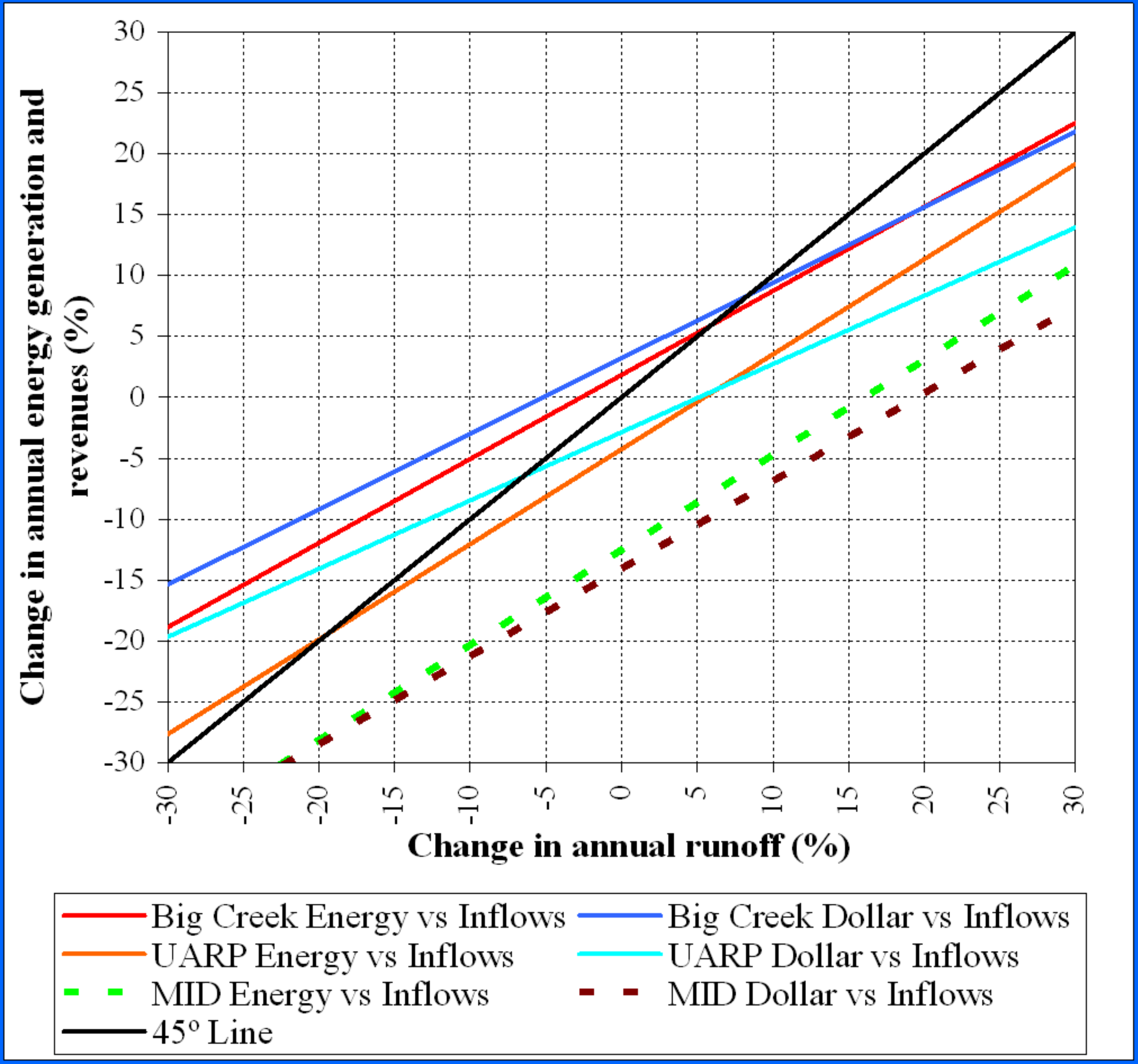
Average Spills in cfs (m^3/s)	2011-2040	137.4 (3.9)	Agriculture Benefits in mill $/year	2011-2040	24.2
	2070-2099	53.60%		2070-2099	-2.8 %

- Agriculture benefits are mostly unaltered
- Large increase in pumping costs (a further reduction in net energy generation)

Relation between change in benefits and inflows



Adaptation strategy

Conjunctive use

	Scenario			Scenario	
Variable	Base	Conjunctive use	Variable	Base	Conjunctive use
Energy Generation	-21.30%	-20.70%	Groundwater Pumping	46.90%	24.50%
Energy Generation revenues	-22.10%	-21.50%	Groundwater Pumping Costs	46.90%	24.50%
Average Spills	53.60%	50.20%	Agriculture Benefits	-2.80 %	-5.80%

Conclusions: Low Elevation Hydropower

- **Hydropower generation drops** and **groundwater pumping increases** under most of climate change scenarios as a consequence drier hydrologic conditions and increased spills.

- **Deficit in net energy** generation for the basin.

- **Agriculture benefits** are mostly not affected

- **System complexity** leaves less room for adaptation. Although some potential alternatives arise (i.e. **conjunctive use**).

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Thank you!

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